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ORIGINAL

AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Invention Title: "Water Desalination"

The invention is described in the following statement:

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"Water Desalination"

Field of the Invention

The invention relates to desalination of brackish or saline water including seawater and groundwater by utilisation of a reverse osmosis process. The invention enables the in situ treatment of such water which can present significant advantages.

Background Art

Osmotic pressure is produced when solutes in aqueous solution at one side of an osmotic membrane are at a chemical potential less than that in pure aqueous solvent (water) located on the other side of the membrane and as a result the solvent naturally permeates through the membrane into the aqueous solution to equalize the chemical potentials thereby exerting an osmotic pressure across the membrane.

In reverse osmosis, pressures greater than the osmotic pressure are exerted on the aqueous solution and this has the effect of inducing the solvent to permeate through the membrane from solution, while the solute is excluded from diffusion and remains behind in solution. Therefore the aqueous solution becomes more concentrated, and water with a low solute concentration accumulates on the other side of the membrane. By this process water can become "desalinated".

Reverse osmosis has become a much more feasible technology for the desalination of non-potable water supplies, and although still more expensive than conventional water abstraction the technology is starting to be used in more remote regions, arid areas where there are few alternatives. Examples of the latter are the oil-rich Gulf states, arid regions in California and elsewhere in the US. In Australia, the Ayers Rock resort at Yulara relies on RO-treated groundwater. Additionally, Perth in WA is looking at commissioning a large seawater desalination plant as backup for conventional supplies during drought.

Desalination by reverse osmosis is energy-expensive generally, as more saline, non-potable water is pumped under pressure through a membrane separation chamber and aqueous solvent diffuses through the membrane whilst salts and contaminants are rejected by the membrane and concentrate in the feed stream. This gives rise to a saline waste which requires proper disposal.

In addition in existing reverse osmosis systems these require facilities for the above-ground storage of the water which is to be desalinated in the reverse osmosis device. This exposes the water to, physicochemical reactions such as iron oxidation and precipitation which can cause membrane clogging which in turn means that the water must be pretreated before desalination.

Disclosure of the Invention

The invention enables the in situ treatment of brackish or saline water including seawater and groundwater by application of the reverse osmosis process within the body of brackish or saline water which can avoid some of the problems of existing systems. In addition the application of the invention can reduce the reliance of pressurisation though pumps and the like which is a characteristic of existing systems.

Accordingly the invention resides in a desalination apparatus comprising a reverse osmosis unit having a membrane, an inlet opening to one side of the membrane and connected to a source of water, a first outlet opening to the one side of the membrane at a position spaced from the inlet, a second outlet opening to the other side of the membrane, the inlet intended in use to be connected to a source of water, the source of water comprising a body of water having an upper surface, the first outlet being intended in use to open into the source of water at a position spaced from the inlet, the second outlet associated with a pumping means adapted to extract solvent permeating through the membrane, the apparatus in use intended to be located below the upper surface to produce a hydrostatic pressure at the one side of the membrane representative of the depth of the apparatus below the upper surface of the column.

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According to a preferred feature of the Invention the second outlet is vented to the atmosphere.

According to a preferred feature of the invention the reverse osmosis unit is adapted to be located within said body of water.

According to a preferred feature of the invention the inlet is connected to the source of water through a pump to generate a pressure at the one side of the membrane which is the sum of the hydrostatic pressure and the outlet pressure of the pump.

According to a preferred feature of the invention the body of water comprises an above ground body of water which can comprise a lake, river, ocean, estuary or like body of water. According to a preferred feature of the invention the first outlet is located lowermost with respect to the inlet and opens directly into the body of water.

According to a preferred feature of the invention the body of water comprises an underground aquifer and the upper surface comprises the water table and/or piezometric surface of the reservoir. According to a preferred feature of the invention the reverse osmosis unit is adapted to be located at the lower end of a bore hole extending into the aquifer. According to a preferred feature of the invention the inlet is associated with a pump which in use is intended to introduce water into the borehole from the source and maintain the pressure at the one side of the membrane which is greater than the hydrostatic pressure. According to a preferred feature of the invention the height is at a level above the upper surface. According to a preferred feature of the invention the first outlet is located lowermost with respect to the inlet and opens directly into the aquifer.

According to a preferred feature of the invention the reverse osmosis unit comprises a at least two first reverse osmosis units connected to the inlet in parallel.

According to a preferred feature of the invention the reverse osmosis unit comprises a second set of reverse osmosis units connected in series downstream from the first set of reverse osmosis units, the first outlet of the second reverse osmosis units being subjected to the hydrostatic pressure of the lower most position of the apparatus which is less than the pressure applied to the one side of the membrane. According to a preferred feature of the invention each of the first and second sets of reverse osmosis units comprise a set of reverse osmosis cells.

According to a preferred feature of the invention the first outlet of the second set of reverse osmosis units is are connected to the body of water through a second pump.

According to a preferred feature of the invention the pump and pumping means comprise a common pump connected to the inlet and the second outlet through a set of valves whereby said common pump is able to introduce said water into the inlet and deliver permeate from the second outlet through a controlled activation of the valves.

According to a preferred feature of the invention the second outlet is vented to the atmosphere.

Throughout the specification the term "piezometric surface" shall be taken to include the water table in an unconfined aquifer or alternatively the piezometric surface of a confined aquifer.

The invention will be more fully understood in the light of the following description of several specific embodiments.

Brief Description of the Drawings

The description is made with reference to the accompanying drawing of which;

Figure 1 is a schematic representation of the operation of the embodiment of the invention;

Figures 2 and 3 are a schematic representation of the first embodiment of the invention; and

Figure 4 is a schematic representation of the second embodiment of the invention.

Detailed Description of the Embodiment

The embodiment applies the concept of lower cost desalination using the process of conventional reverse osmosis, through the use of downhole technology where the source of water is brackish, saline or polluted groundwater. The proposed in situ treatment is semi-passive in nature, in that the required pressures across the membrane are produced from a combination of natural hydrostatic pressure of groundwater along with an induced pressure from low-rate pumping (together constituting P_1) and removal of fresh water from within the membrane chamber, again by pumping, to give a lower hydrostatic pressure (P_2) within this chamber. The pressure difference ΔP ($P_1 - P_2$) drives the reverse osmosis process (Figure 1).

The in situ system also can be engineered to naturally dissipate wastewater products of reverse osmosis back into the aquifer, utilizing the density difference between natural saline groundwater and reverse osmosis effluent. Thus within a borehole, the more dense and saline effluent moves vertically under gravity, "fingering" through less dense groundwater and accumulating at the base of the borehole.

The likely reverse osmosis well configuration is for a dual-screen well, with the topmost screen allowing saline groundwater ingress to the downhole reverse osmosis device, whilst the lower screen allows saline effluent to dissipate within the naturally saline aquifer. The two screens can be separated by an inflatable straddle packer, common in downhole operations.

The principle of operation of the embodiments are illustrated schematically at Figure 1 and illustrates a bore hole 11 having a screened portion 13 at its lower end. The bore hole accommodates a reverse osmosis unit 15 which has an inlet 17. The inlet is associated with a vertical piezometer tube 19 which extends upwardly through the bore hole from the reverse osmosis unit to the upper end of the bore hole and which provides a means of measuring the pressure applied to the inlet 17 of the reverse osmosis unit.

In addition the reservoir is associated with a pump 23 which delivers water from the aquifer to the inlet 17 to maintain the pressure at the inlet greater than the inherent water pressure exerted on the unit.

The reverse osmosis unit 15 is provided with a first outlet 25 which and which is open to the one side of the membrane common to the inlet 17. The first outlet 25 is lowermost such that the denser reject solution from the reverse osmosis unit 15 will flow under the influence of gravity downwardly into the aquifer. In addition the pressure at the first outlet comprises the inherent water pressure exerted on the unit which will be less than that exerted on the outlet.

The reverse osmosis unit 15 is also provided with a second outlet 27 which opens to the other side of the membrane and is intended to receive the permeate flowing through the membrane. The second outlet is associated with a further pump (not shown) which serves to extract the permeate from the second outlet. In addition the second outlet is vented to atmosphere.

The utilisation of the first pump 23 to deliver water from the aquifer to the inlet 17 enables the pressure at the inlet 17 to be above the inherent pressure surrounding the reverse osmosis unit and to control the magnitude of the hydrostatic pressure applied to the one side of the membrane through the inlet 17. The magnitude of the pressure differential between the finlet and the first outlet 25 will be determined by the delivery pressure of the pump.

The embodiments use conventional reverse osmosis cells where the feed solution is pumped from close to the screened interval within the well to give a

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pressure or head of water (P1) which drives the feed solution through the reverse osmosis device. The hydrostatic pressure also allows fresh water to permeate through the membrane and accumulate as product on the low pressure side of the membrane. Low pressure on the permeate side of the membrane is maintained by the pumping of permeate to the surface. It is expected that, high permeate flow rates should be possible if hydrostatic pressure heads are of the same order as those in conventional reverse osmosis systems (eg 10-12 atmospheres, or 100-120m head of water).

The principle of each of the embodiments involves the use of down-hole hydrostatic head conditions to drive the reverse osmosis process and thus potentially provide energy savings over conventional reverse osmosis systems where pressure is obtained using energy-demanding inlet and outlet pumping. In comparison the embodiments involve the use of relatively low-rate down-hole pumping required to lift the permeate to the surface and to maintain the pressure at the inlet greater than the inherent pressure of the body of water surrounding the unit.

The rate of removal of reject solutions from the reverse osmosis device into lower parts of the borehole is driven to a large extent by the applied hydraulic head induced by pumping into the inlet and because it is more saline than the groundwater used for feed to the inlet, the downward vertical flow of the reject solution through the aquifer will be induced through density contrast.

The first embodiment as illustrated at Figures 2 and 3 and comprises an arrangement in which the inlet 17 of the reverse osmosis unit or array of units is provided with a feed pump 23 which will deliver the ground water to the inlet at a pressure greater than the inherent hydrostatic pressure at the inlet. The permeate is delivered into a storage reservoir 31 from the second outlet 27 and the storage reservoir is provided with a second pump 33 for extracting permeate from the storage reservoir. The storage reservoir is vented to atmosphere through a tube 35.

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The reverse osmosis unit 15 comprises three reverse osmosis units 15a, 15b and 15c which each comprise a set of reverse osmosis cells connected in series. The units are located longitudinally within the bore hole. The feed pump 23 delivers groundwater from the aquifer into the two lower most units 15a and 15b such that the first and second units are essentially connected in parallel in relation to the reservoir and feed pump. The inlet 17 for each unit is located lowermost and each cell of each unit has a second outlet 27 which delivers permeate to a common delivery line connected to a pump 9 (not shown). In addition the upper most cell of each unit is connected to the first outlet 23 whereby reject from the first and second units 15a and 15b are introduced into the inlet for the uppermost third unit 15c. In the third unit 15c each reverse osmosis cell has a second outlet which delivers permeate to the common delivery line. The uppermost reverse osmosis unit 15c is provided with a first outlet which communicates via an outlet conduit into the lowermost end of the bore hole. The arrangement of the embodiment as shown at Figures 2 and 3 is illustrative of just one possible configuration arranged for in situ reverse osmosis, and there many other such configurations which could be used.

A second embodiment as illustrated at Figure 4 applies to a circumstance where there is sufficient hydrostatic head in the bore hole to provide a significant pressure differential across the membrane of the reverse osmosis units with a minimal additional pumping of feed from the aquifer being required. This situation is likely to apply the case of deeper, confined or semi-confined aquifers. In the case of the fourth embodiment the device utilises a single pump 23 which has an inlet which is open to the interior of the bore hole screen through a feed line 35 and a first control valve 37 to receive water contained within the bore hole and feeding this water to the inlet 17 of the reverse osmosis unit 15 through a first delivery line 39 via a second control valve 41. In addition the pump 23 is connected to the storage reservoir 31 through a second inlet line 43 and a third control valve 45 and has a second outlet connected to a permeate delivery line 47 through a fourth control valve 49. The permeate storage reservoir 31 is vented to atmosphere for pressure equalisation through tube 36. When the third and fourth control valves 45 and 49 are closed and the first and second control

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valves 37 and 41 are open the operation of the pump serves to deliver feed water through the first delivery conduit 37 through the pump and to the second delivery conduit 39 and then to the reverse osmosis unit 15 at a pressure greater than the hydrostatic pressure at the lower most point of the first outlet 25 of the apparatus. When the first and second valves 37 and 41 are closed and the third and fourth control valves 45 and 49 are open the permeate in the storage reservoir can be delivered through the permeate delivery conduit 47 to the surface. The pressure within the reverse osmosis unit would stabilise and equal the hydrostatic pressure at the first outlet 25 during periods when permeate is being removed which allows the reverse osmosis process to continue.

The reverse osmosis units of each of the above embodiments can take the form of any conventional reverse osmosis unit which can be modified and configured to be receivable within a bore hole. One form of reverse osmosis unit comprises cells in the form of a spiral wound element formed by a strip wound around a central cylindrical element where the strip is a composite element formed from sheets of membrane to either side of a central water porous sheet with porous spacers provided along each external surface of the composite sheet. Feed water is delivered into the space surrounding the external faces of the composite sheet whilst the permeate is extracted from the porous sheet located between the two sheets of membrane.

Alternatively hollow-fibre reverse osmosis cells could be configured for use with the embodiments. Conventionally these incorporate small diameter, hollow membranes with internal, porous support medium in a high pressure vessel into which the feed solution is delivered where the permeate is collected from the interior of the hollow fibres.

Conventionally reverse osmosis membranes can lose their permeability due to fouling from particulates, from filtering of colloidal sized particles, from precipitation of mineral scales as salts concentrate around the membrane, and from bacterial fouling. Therefore each reverse osmosis application has to take

these aspects into account and feed water pre-treatment may be necessary with in situ reverse osmosis treatment according to each of the embodiments.

As the solutes concentrate in the aqueous solution during the reverse osmosis process, mineral species can become saturated or supersaturated and as a result precipitate out to form scales. In this regard carbonate minerals (calcite, aragonite, siderite) and sulphate minerals such as gypsum [CaSO4.2H2O], anhydrite [CaSO4], barite [BaSO4] and celestite [SrSO4], fluorite [CaF2] and silica are typical, common minerals known to form scales. To avoid this problem antiscalants can be added to the feed to counteract scale formation. Thus acids can be added to feed water to reduce carbonate ion concentration and form bicarbonate ions and carbonic acid and thus reduce saturation with respect to carbonate minerals. Other antiscalants are used and serve to inhibit the formation of precipitates so that small crystal nuclei can be removed from the membrane in feed flow. It is anticipated that it will be possible to add antiscalants to the feed water in the case of each of the embodiments, so these problems are likely to give rise to no greater problems than is the case with conventional systems. However it is also possible that systems according to the embodiments devices may be operated at low pressures with lower overall concentrations in reject solutions, which will result in a reduced likelihood of scale formation.

In addition prefiltration is nearly always recommended to protect membranes with a minimum filter pore size of 5 microns from clogging,. This would probably be required for each of the embodiments but it is anticipated that conventional sand/gravel packs which are used in properly constructed wells may provide adequate filtration. However while this level of filtration would remove suspended solids it will not remove the "turbidity" typical of colloidal sized suspended solids. Such colloids form, for example, as reduced and more soluble ferrous and manganous ions in groundwater are oxidized on exposure to atmospheric oxygen to their less soluble forms. The resultant precipitated oxyhydroxide minerals form colloidal suspensions and hence give rise to turbidity

in the groundwater. High rates of pumping can also mobilize colloidal sized clay particles in the aquifer, giving rise to turbidity.

It is anticipated that in the case of the embodiments where low flow rates are used in feed to the reverse osmosis units, and where there is no direct contact of the downhole reverse osmosis system with the atmosphere that there will be, reasonable protection from water turbidity and the formation of colloidal suspensions compared with more conventional reverse osmosis systems.

Therefore, if the well construction is good, particularly relating to the sand/gravel pack around the well screen then larger suspended particle sizes would seem less likely to have an impact on the reverse osmosis membrane, and relatively coarse filtration may be the only treatment necessary.

Natural bacteria are endemic in groundwater systems, even deeper aquifers which have low dissolved carbon, low nutrient and often anoxic conditions. Under these low energy conditions, bacteria numbers are low, and bacterial activity is very subdued compared to that in soils and in shallow aquifers. Deeper groundwaters also tend not to be contaminated by pathogenic bacteria and viruses which are more common in shallow groundwaters, eg from sewage contamination. Bacteria can cause problems in groundwater supply wells, particularly from iron oxidizing bacteria which form iron scales within the well screen and gravel pack, leading to well clogging. These bacteria are aerobic, requiring a ready supply of dissolved oxygen which is derived from aeration of groundwater during rapid drawdown and recovery of water levels in and immediately around the supply well during pumping and pump shutdown. The problem is much less prevalent in deeper, semi-confined aquifers, where oxygen ingress is less likely. Low-flow pumping, as proposed in the case of the embodiments would also preclude oxygen ingress. Therefore it is anticipated that in the case of each of the embodiments that the reverse osmosis treatment is unlikely to be impacted from bacterial activity, particularly from production of bacterial slimes which could clog reverse osmosis membranes.

In comparison with convention reverse osmosis desalination plants it is envisaged that the plant according to the invention will be more economically viable when compared with other sources of potable water. The plant according to the embodiments would not require a number of the capital items which are required of conventional reverse osmosis installations. Since most of the infrastructure is below ground and there is no requirement for extensive building structures or for water storage which is provided naturally by the aquifer. It is assumed that costs of the downhole RO system itself would be similar to those for a conventional above ground application and the cost for the provision of "feed water" (i.e. drilling of wells to obtain brackish groundwater) would be the same in both cases. However there would be no requirement for high volume pumping as is the case with conventional reverse osmosis systems, and there is no requirement for high-pressure pumping, except for the recovery of permeate. Taking these possible savings into account, construction costs for a desalination plant according to the embodiments could be quite considerable when compared to a conventional desalination plant utilising a conventional reverse osmosis system.

It is also anticipated that operational costs will be less with electric power requirements likely being less and with reject disposal costs being negligible.

Disposal of reject solutions in conventional reverse osmosis applications is often problematic, and with any such *in situ* treatment system such as in the embodiments described here where reject is disposed back into the reservoir from which the feed came, the impact of this disposal method would need to be assessed and approved by regulatory agencies and jurisdictions. In particular, the beneficial use or environmental value of the reservoir or aquifer resource should not be unduly affected by such disposal of reject solution. Given the likelihood that brackish or saline aquifers would have no value for drinking water for humans or animals, or for irrigation purposes, then the main consideration would be environmental water use, in relation to aquifer ecosystem itself, or discharge of groundwater to surface ecosystems. In cases where surface

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discharges are absent or where there is discharge to a terminal drainage system such as the ocean or a salt lake, then impacts are likely negligible.

Thus the desalination plant according to the invention offers reduced overall capital and operational costs, as well as low visual impact of minimal above-ground infrastructure, whilst also avoiding problems from disposal of reject solutions at the surface. Overall, the system potentially should offer equivalent performance at lower overall capital, operational and environmental costs.

Throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

It should be appreciated that the scope of the present invention need not be limited to the particular scope of the embodiment described above. In particular whilst the embodiments are each directed to down hole installations the invention need not be so limited and can have application to above ground installations.

Dated this fifteenth day of January 2004.

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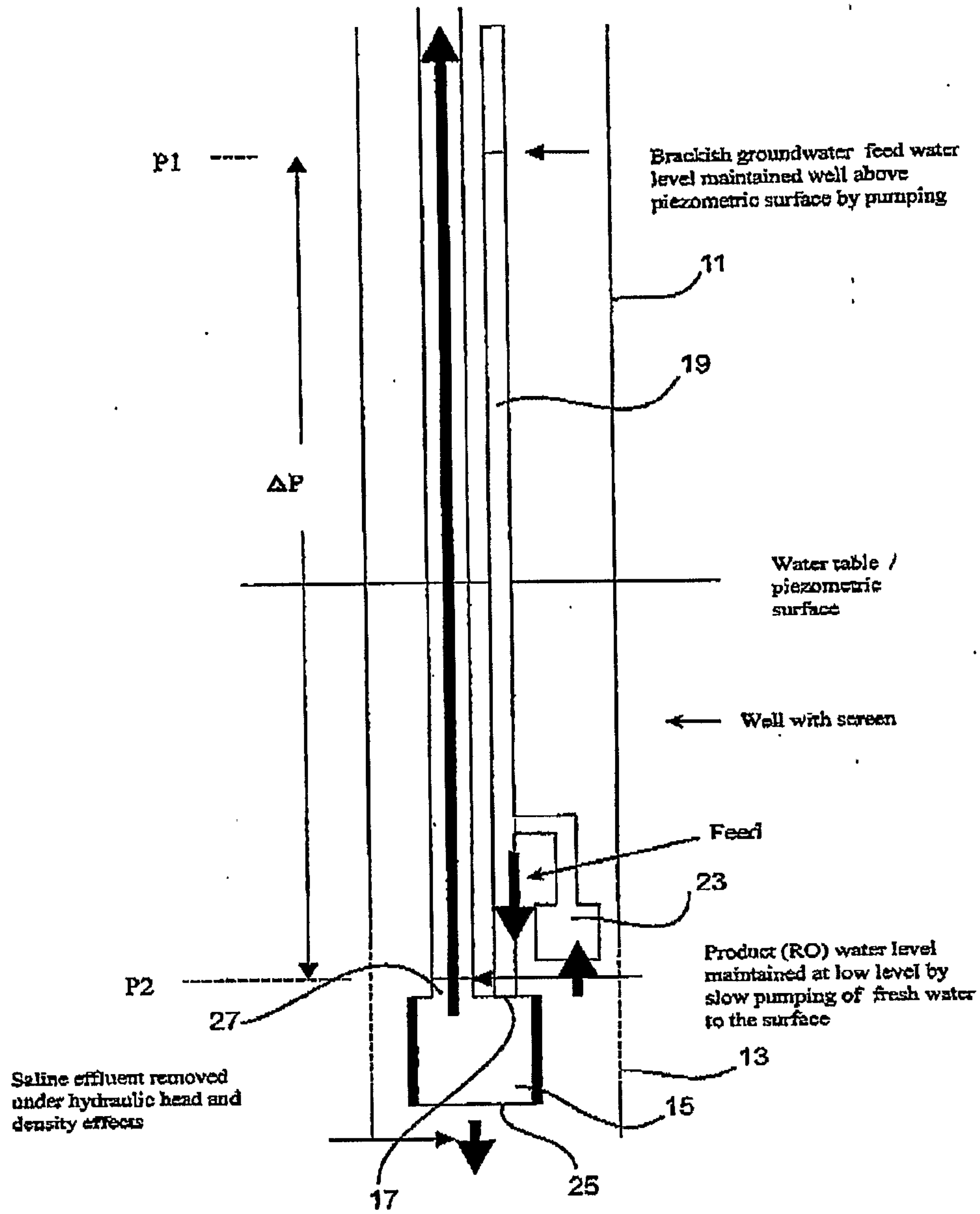
P1
Brackish groundwater feed water level maintained well above piezometric surface by pumping
11
19
ΔP
Water table / piezometric surface
Well with screen
Feed
23
Product (RO) water level maintained at low level by slow pumping of fresh water to the surface
P2
27
13
Saline effluent removed under hydraulic head and density effects
15
17
25

Fig.1.

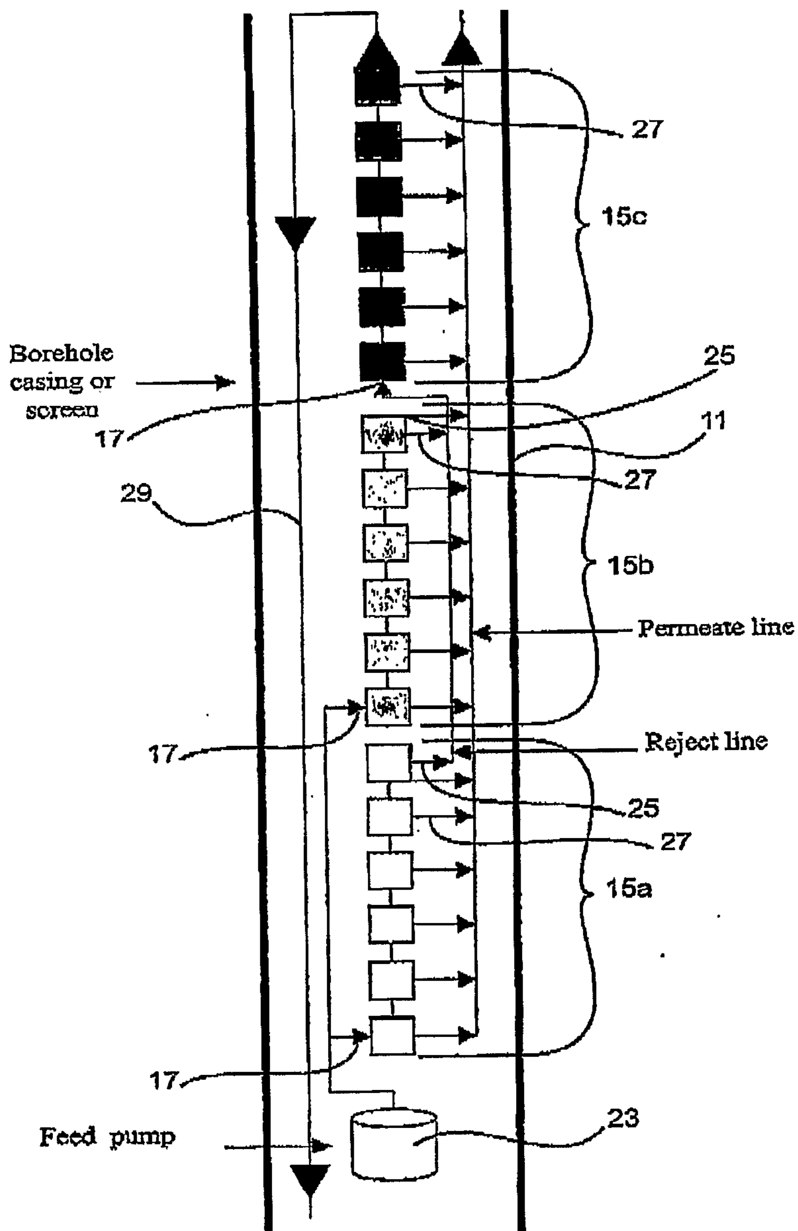
27
15c
Borehole casing or screen
25
17
11
27
29
15b
Permeate line
17
Reject line
25
27
15a
17
23
Feed pump

Fig. 2.

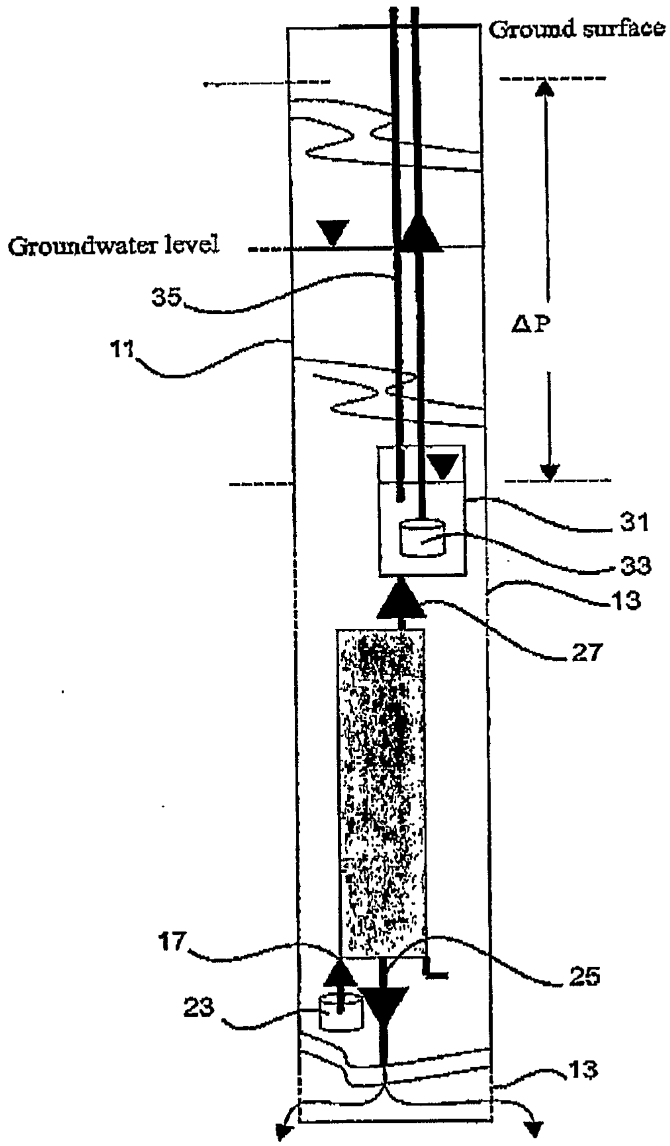
Ground surface
Groundwater level
ΔP
35
11
31
33
13
27
17
25
23
13

Fig. 3

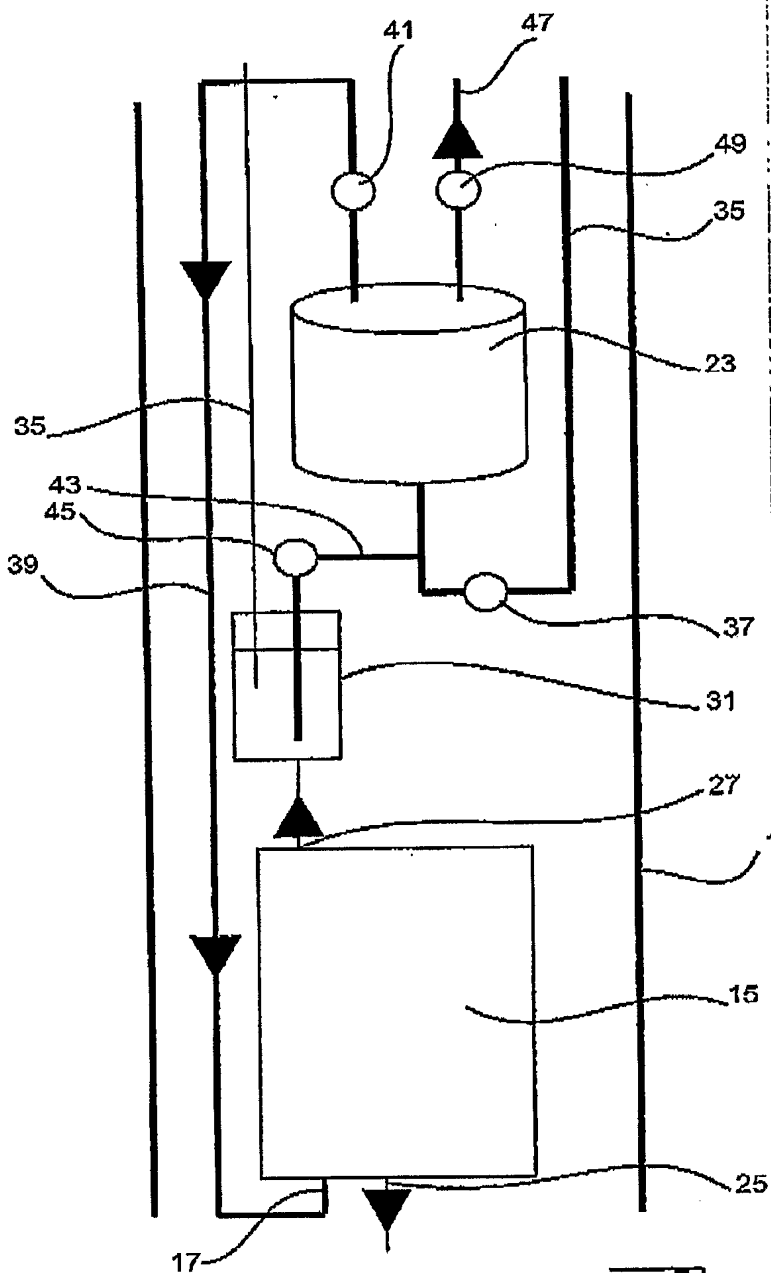

Fig. 4